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Spiral Chip Implantable Radiator and Printed Loop External Receptor for RF Telemetry in Bio-Sensor Systems

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Abstract — **The paper describes the operation of a patented wireless RF telemetry system, consisting of a bio-MEMS implantable sensor and an external hand held unit, operating over the frequency range of few hundreds of MHz. A MEMS capacitive pressure sensor integrated with a miniature inductor/antenna together constitute the implantable sensor. Signal processing circuits collocated with a printed loop antenna together form the hand held unit, capable of inductively powering and also receiving the telemetry signals from the sensor. The paper in addition, demonstrates a technique to enhance the quality factor and inductance of the inductor in the presence of a lower ground plane and also presents the radiation characteristics of the loop antenna.**

I. Introduction

The biological and physical sciences program at NASA seeks to develop telemetry based implantable sensing systems to monitor the physiological parameters of humans during space flights [1]. This focus is rather unique when compared to efforts by other investigators, which have been mainly in the area of RF/microwave applications in medical treatment and biological effects [2]. In two recent papers [3], [4], the authors have presented the development of a micro inductor/antenna for implantable bio-microelectromechanical systems (bio-MEMS) based capacitive pressure sensors and a printed multi-turn loop antenna for an external hand held unit, respectively. In the above developmental effort, the loop antenna through the inductor/antenna activates and also acquires RF telemetry data from the implanted sensor. In addition to the above, a third paper by the authors demonstrated signal coupling through stratified media represented by muscle tissue-like and fatty tissue-like phantoms placed between the micro inductor/antenna and the loop antenna [5].

In this paper, we further advance the development of the implantable inductor/antenna by taking into consideration the presence of an inevitable lower ground plane and its influence on the inductance and quality factor. In addition, we also investigate the radiation patterns of the printed multi-turn loop antenna in the external hand held unit. The above investigations are covered by two patent applications, one of which has been recently granted [6], [7].

II. Wireless RF Telemetry System

The contact-less powering and telemetry concept, including the miniature square spiral inductor/antenna circuit intended for integration with a MEMS pressure sensor, is illustrated in Fig. 1(a). The pressure sensor is of the capacitive type and is located in the annular region of the inductor. The inductor behaves both as an inductance as well as an antenna thereby allowing the sensor to receive as well as radiate out energy. In the receive mode, the inductance picks up energy and charges the MEMS pressure sensor diaphragm capacitance. In the transmit mode, the above inductance and capacitance form a parallel resonant circuit and radiate energy through the inductor which now behaves as a planar spiral antenna. To obtain a pressure reading, a pulse emitted by the hand held unit initially interrogates the sensor. At the rising and the falling edges of this pulse a voltage is induced in the spiral inductor thus implementing contact less powering. The waveform of this induced voltage is a decaying sine wave. These oscillations also cause the inductor to radiate energy that is picked up as a telemetry signal by the receiving antenna in the hand held unit. Since the inductance of the implanted sensor circuit is fixed, the frequency of the decaying sine wave is mainly determined by the capacitance introduced by the sensor. Thus, the larger the pressure difference, the larger the frequency offset between the received telemetry in the two pressure states. The implanted bio-MEMS sensor and the hand held unit together form the wireless RF telemetry system [6], [7] as illustrated in Fig. 1(b).

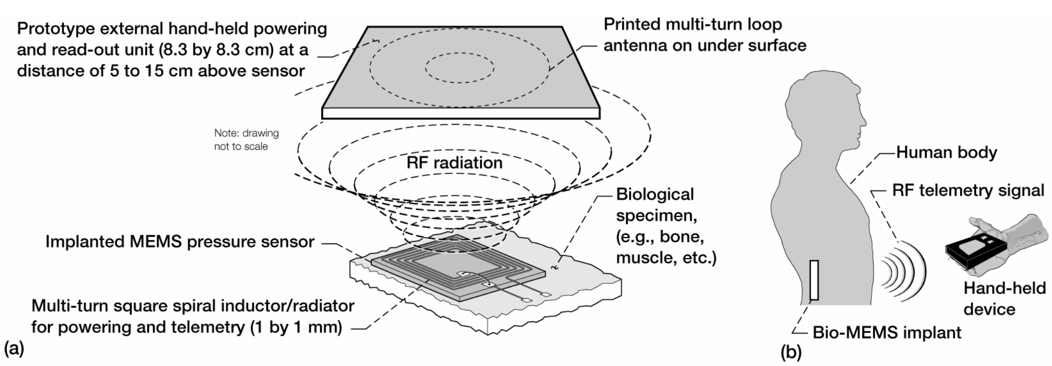

Fig. 1. Contact-less powering and telemetry. (a) Concept. (b) Application in biosensors.

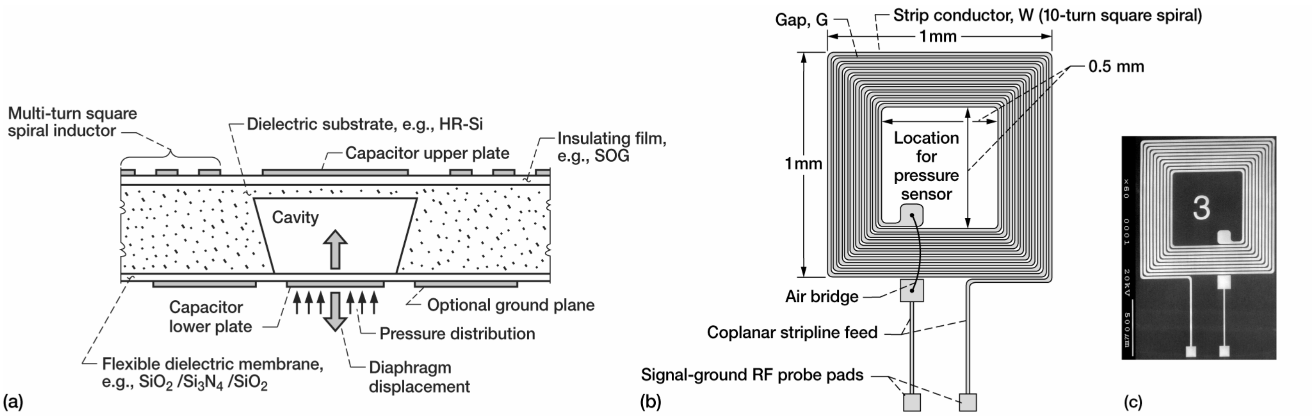

Fig. 2. (a) Schematic of a capacitive pressure sensor. (b) Schematic of a miniature spiral inductor/antenna on SOG/HR-Si wafer. (c) Photomicrograph of inductor/antenna.

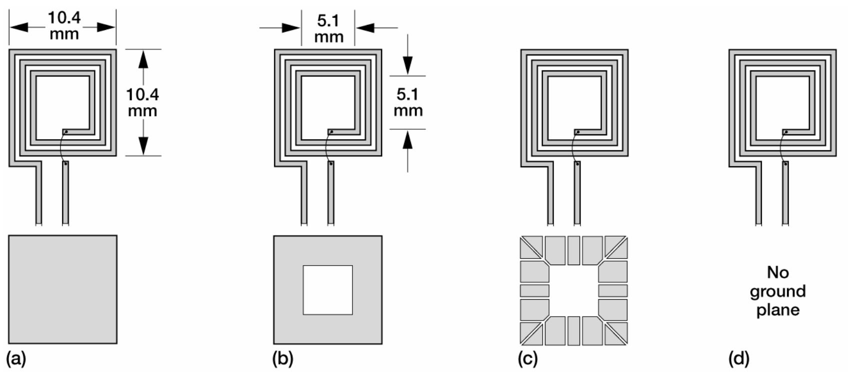

Fig. 3. Top and bottom view of square spiral inductor with various ground patterns. Substrate is Duroid®. The strip conductor and gap widths are 0.635 mm and 0.381 mm, respectively. (a) Solid full ground plane. (b) Solid ring ground plane. (c) Serrated ring ground plane. (d) No ground plane.

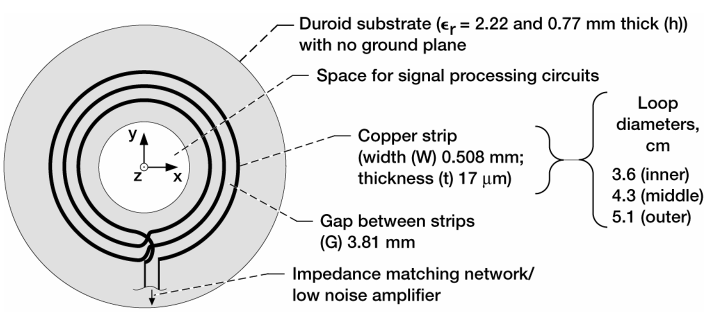

Fig. 4. Printed multi-turn loop antenna on a dielectric ring.

III. Pressure Sensor and Square Spiral Chip Inductor/Antenna

A schematic rendition of the pressure sensor is shown in Fig. 2(a). The pressure sensor consists of a diaphragm suspended over a cavity micromachined from a silicon wafer and is of the capacitive type with capacitance change in the range of 0.3 to 4 pF [3].

Figure 2(b) shows a schematic of the square spiral chip inductor/antenna. The outer dimensions of the inductor are about 1×1 mm, and the inductor is fabricated on a spin-on-glass (SOG) coated high resistivity silicon (HR-Si) wafer to reduce the attenuation of the signals. An initial estimate based on the capacitance values of the pressure sensor show that an inductance (L) with a quality factor (Q) of about 150 nH and 10 respectively, are adequate for the application described above. The frequency range over which this device is intended to operate is from 200 to 700 MHz which includes the Federal Communications Commission (FCC) designated bands. Figure 2(c) shows a SEM picture of a typical inductor/antenna circuit. The fabrication procedures as well as the results of a parametric study of these inductors are presented in [3].

The presence of a parasitic lower ground plane introduced by the capacitive pressure sensor degrades the inductance and quality factor of the inductor. Hence, to investigate these problems spiral inductors with different types of ground planes as illustrated in Fig. 3 were fabricated. In the initial phase of the study, the inductors were expeditiously fabricated on low cost copper-clad Duroid® (registered trademark of Rogers Corporation) substrates and evaluated. From this study, the most promising design was picked and transferred to silicon, which is the material of choice for the sensor. Subsequently, several inductors based on this design concept were fabricated on a HR-Si wafer.

IV. Printed Multi-Turn Loop Antenna

The printed multi-turn loop antenna in the hand held unit is illustrated in Fig. 4. For maximum sensitivity, the input impedance of the loop antenna is matched by a lumped element PI-network to the 50 Ω input impedance of the MMIC low noise amplifier (LNA) chip in the receiver. The circuit and fabrication details of the antenna are presented in [3].

V. Experimental Results And Discussions

A. Inductance of Square Spiral Inductor with Different Types of Ground Planes on Duroid ®

The circuits are experimentally characterized by measuring the return loss S_{11} using on-wafer RF probing techniques. From the measured S_{11}, the inductance L and the quality factor Q are analytically determined. Figure 5 shows the inductances as a function of the frequency for inductors with four types of ground planes. It is observed that the inductance degrades in the presence of either a solid full or a solid ring ground plane. This is because the image current in the aforementioned ground planes flows in a direction opposite to the current on the spiral thereby reducing the magnetic field and thus the overall inductance [8], [9]. In contrast, it is interesting to observe that the inductance of the inductor with a serrated ring ground plane is about the same as that of an inductor without a ground plane. This is because the slots in serrated ground plane act as open circuits and thus suppress the flow of image current [8], [9].

B. Quality Factor of Square Spiral Inductor with Different Types of Ground Planes on Duroid ®

The peak Q value for the four inductors shown in Fig. 3 are presented in Table I. It is interesting to note that the peak Q for the inductors with and without a serrated ground plane is about the same. From this initial study of L and Q it was concluded that the serrated ground plane is ideally suited for mitigating image current effects.

C. Inductance and Quality Factor of Square Spiral Inductor with Serrated Ground Plane on High Resistivity Silicon Wafer

The L and Q of the inductors in previously reported studies [3] were without a lower ground plane. From that study it was evident that peak Q and corresponding L as high as 10.5 and 153 nH respectively were achievable. To investigate the effect of the lower ground plane, this inductor was reproduced on a HR-Si wafer with a serrated ground plane on the opposite side. The measured Q and L as a function of frequency are presented in Fig. 6. The peak Q and the corresponding L are about 8.2 and 130 nH, respectively. By comparing the two sets of results it is evident that there is a small degradation in the peak Q and corresponding L values. Nevertheless, the serrated ground plane clearly demonstrates its efficacy to mitigate image currents effects.

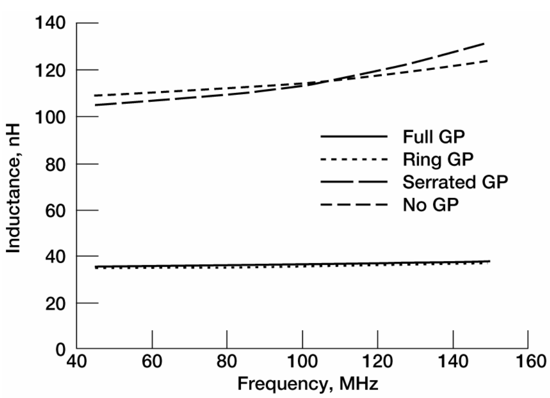

Fig. 5. Measured inductance of square spiral inductors with different types of ground planes (GP) on Duroid® substrates.

TABLE I
SPIRAL INDUCTOR QUALITY FACTOR WITH DIFFERENT TYPES OF GROUND PLANES

Ground Plane Type	Quality factor
Solid Full Ground Plane	40.6
Solid Ring Ground Plane	37.3
Serrated Ring Ground Plane	73.0
No Ground Plane	78.3

Material: Duroid®, Substrate Dielectric Constant: 10.5
Substrate Thickness: 0.254 mm, Conductor: Copper
Conductor Thickness: 17 µm, Frequency: 230 MHz

D. Radiation Pattern of Printed Multi-Turn Loop Antenna

In Fig. 7, the experimental setup for measuring the radiation patterns of the multi-turn loop antenna in the hand held unit and the coordinate system are schematically illustrated. A short dipole antenna is used as the transmitting antenna. In a typical medical diagnostic situation, the radiation emanating from the implanted chip radiator may be vertically, horizontally or slant polarized. Hence, to emulate all possibilities, the radiation

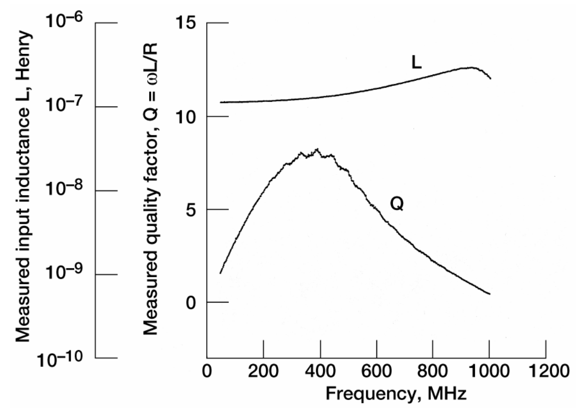

Fig. 6. Measured inductance and quality factor for an inductor with a serrated ring ground plane on a HR-Si wafer. No SOG layer. The thickness of the gold conductor on the top and bottom are about 1.5 µm and 1.8 µm, respectively. The wafer thickness is about 400 µm.

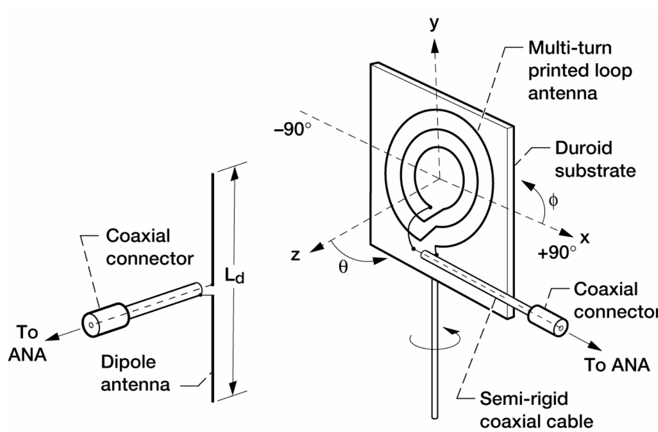

Fig. 7. Schematic illustrating the experimental setup for measuring the loop antenna radiation patterns using an automatic network analyzer (ANA) and the coordinate system. The dipole length L_d is about 0.1 λ_0, where λ_0 is the free space wavelength at the measurement frequency.

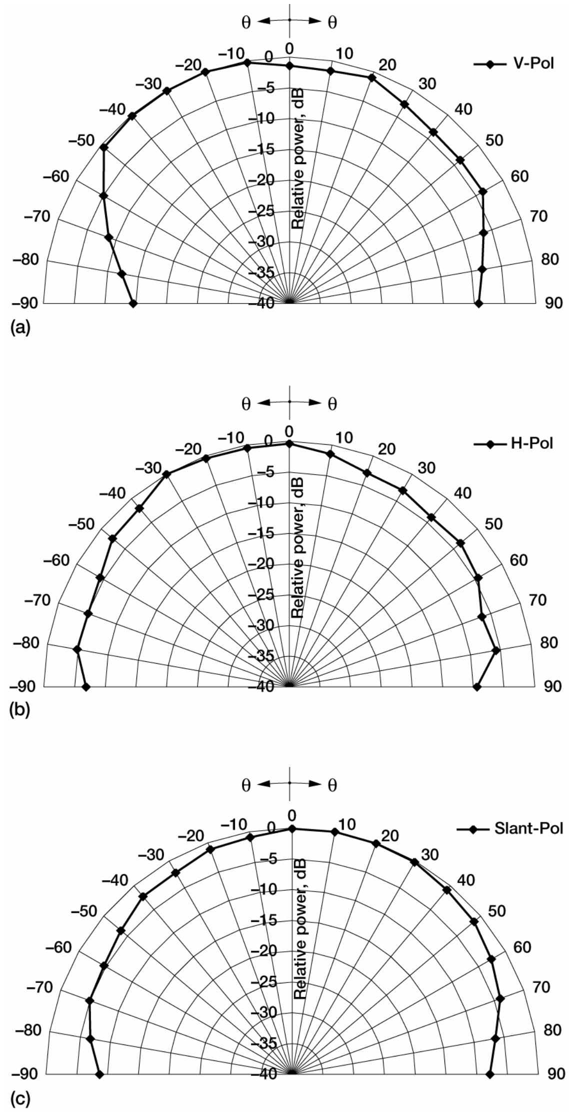

Fig. 8. Measured radiation patterns of the loop antenna at 330 MHz in the $\phi = 0°$ or x-z plane when the incident wave is: (a) Vertically polarized (y-axis). (b) Horizontally polarized (x-axis). (c) Slant polarized (45°).

pattern of the loop is measured with the transmitting dipole vertically, horizontally, and slant (45°) polarized. In Fig. 8, the measured radiation patterns of the multi-turn loop in the $\phi = 0°$ or horizontal (x-z) plane are presented. Since the loop antenna is symmetric it is expected to have similar patterns in the $\phi = 90°$ or vertical (y-z) plane also. From these measurements it is inferred that the loop is a very versatile antenna capable of providing hemispherical coverage and also receiving signals with any of the above polarizations.

E. Received Relative Signal Strength

To emulate a typical operating condition in a medical diagnostic application, the hand held unit with the loop antenna is held at a height of 10 cm and coaxial with the inductor. The measured relative signal strength magnitudes are presented in [3] and [5]. It is observed that at the frequency of best impedance match, the loop is capable of discriminating against noise with better than 20 dB signal-to-noise ratio.

VI. Conclusions

The development of a wireless RF telemetry system, consisting of a bio-MEMS implantable sensor and an external hand held unit, operating over the frequency range of few hundreds of MHz is presented. In addition, the use of a serrated ground plane instead of a continuous ground plane to mitigate detrimental effects of image currents on inductance and quality factor of printed inductors is demonstrated. Furthermore, radiation pattern measurements demonstrate that the multi-turn loop antenna in the hand held unit is capable of providing hemispherical coverage and also receiving signals emanating from the implanted sensor with vertical, horizontal or slant polarization.

References

[1] J.W. Hines, "Medical and Surgical Applications of Space Biosensor Technology," Acta Astronautica, Vol. 38, Nos. 4–8, pp. 261–267, Feb.–April 1996.

[2] Mini-Special Issue on RF/Microwave Applications in Medicine (Part I) and Special Issue on Medical Application and Biological Effects of RF/Microwaves (Part II), IEEE Trans. Microwave Theory Tech., Vol. 48, No. 11, Nov. 2000.

[3] R.N. Simons, D.G. Hall, and F.A. Miranda, "RF Telemetry System for an Implantable Bio-MEMS Sensor," IEEE MTT-S Inter. Microwave Symp. Digest, Vol. 3, pp. 1433–1436, Fort Worth, TX, June 6–11, 2004.

[4] R.N. Simons, D.G. Hall, and F.A. Miranda, "Printed Multi-Turn Loop Antenna for RF Bio-Telemetry," IEEE Antennas and Propagation Society Inter. Symp. Digest, Vol. 2, pp. 1339–1342, Monterey, CA, June 20–25, 2004.

[5] F.A. Miranda, R.N. Simons, and D.G. Hall, "Validation of Radio Frequency Telemetry Concept in the Presence of Biological Tissue-Like Stratified Media," IEEE Antennas and Propagation Society Inter. Symp. Digest, Vol. 2, pp. 1335–1338, Monterey, CA, June 20–25, 2004.

[6] R.N. Simons and F.A. Miranda, Radio Frequency Telemetry System for Sensors and Actuators, U.S. Patent No. 6667725, Dec. 23, 2003.

[7] F.A. Miranda and R.N. Simons, Hand Held Device for Wireless Powering and Interrogation of Bio-MEMS Sensors and Actuators, LEW 17, 483–1, July 2003.

[8] C.P. Yue and S.S. Wong, "On-Chip Spiral Inductors with Patterned Ground Shields for Si-Based RF IC's" IEEE Jour. Solid-State Circuits, Vol. 33, No. 5, pp. 743–752, May 1998.

[9] C.A. Chang, S.-P. Tseng, J.Y. Chuang, S.-S. Jiang, and J.A. Yeh, "Characterization of Spiral Inductors With Patterned Floating Structures," IEEE Trans. Microwave Theory Tech., Vol. 52, No. 5, pp. 1375–1381, May 2004.

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13. ABSTRACT ***(Maximum 200 words)***

The paper describes the operation of a patented wireless RF telemetry system, consisting of a bio-MEMS implantable sensor and an external hand held unit, operating over the frequency range of few hundreds of MHz. A MEMS capacitive pressure sensor integrated with a miniature inductor/antenna together constitute the implantable sensor. Signal processing circuits collocated with a printed loop antenna together form the hand held unit, capable of inductively powering and also receiving the telemetry signals from the sensor. The paper in addition, demonstrates a technique to enhance the quality factor and inductance of the inductor in the presence of a lower ground plane and also presents the radiation characteristics of the loop antenna.

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